



Responsible Land Governance: Towards an Evidence Based Approach

ANNUAL WORLD BANK CONFERENCE ON LAND AND POVERTY
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SOIL MOISTURE DETERMINATION USING REMOTE SENSING DATA FOR THE PROPERTY PROTECTION AND INCREASE OF AGRICULTURE PRODUCTION

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Abstract

Today we are witnesses of global climate changes confirmed by the temperature increase in past 100 years which cause more frequent natural disasters across the globe. In the past six years, the environment in Serbia had suffered great changes when several natural disasters occurred (forest fires, drought, flooding's). In 2012 the entire territory was affected by extreme drought, and according to the unofficial data, the Government allocated about €150 million to redress its effects. According to the Serbia floods 2014 Recovery Assessment Report, the total amount of the damage and effects is over €1,700 million. Altogether the damage amounts to approximately €1.9 billion. To provide geospatial data that enables generation of adequate information related to floods and droughts, we applied the remote sensing method that relies on the use of soil moisture index (SMI) which in its algorithm uses the data obtained from satellite sensors. As presented by Hunt et al., the index is based on the actual content of water (Θ), water capacity and wilting point. Multispectral satellite images from visible (red band) and infrared bands (near infrared and thermal bands) are essential for the calculation of the index.

Key Words: Climate change, Soil moisture index (SMI), Remote sensing, Flood, Drought



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Introduction

Global climate changes are confirmed by the temperature increase in past 100 years. According to EPA¹ data, today temperature is 1°C increased about the same year in a previous century, whereas the predictions for the next 100 years are up to 8°C, 3-5°C by the end of the XXI century. Floods, droughts, forest fires and other natural disasters are more frequent across the globe. The struggle with the nature of these disasters is comprehensive and requires the involvement of a vast number of people to repair and rebuild the damage and conduct the adequate protection. Climate change that causes natural disasters, directly affect the quality of human lives and has a significant impact on agricultural production. Previous climatologic data that are still in use in agricultural research changed dramatically, and it is of great significance their revision and update. To facilitate the struggle with changes in nature and speed up the remediation of consequences, use of modern methods and techniques is not only desirable, but it is rather necessary. These technologies and methods include GIS analysis and processing of the data obtained by remote sensing technology (LiDAR, Radar, Satellite images and others).

In the past six years, the environment in Serbia had suffered great changes when several natural disasters occurred (forest fires, drought, flooding's, etc.). Due to the climate change, a significant number of landslides have occurred, many houses have been destroyed, agricultural yields has been reduced, the amount of toxic/carcinogenic substances increased in agricultural products. The sustainable development as planned and as we apply begins to lose its basis, and critical revision is necessary if we want to be ready for the upcoming future.

According to the Recovery Assessment Report „Serbia Floods 2014“, 24 municipalities were characterized as the most affected by the floods that occurred during the third week in May 2014, where the precipitation was more than 200mm per sq m during one week. The damage (total effect) which emerged after the floods in these municipalities was estimated at €1,525 million, of which 57% relates to the value of the destroyed properties, while the remaining 43% relates to the losses in the agriculture production (Serbia Floods, 2014). According to data from the same document, the total amount of the damage and effects caused by these floods is over €1,700 million for all affected municipalities in the Republic of Serbia.

In contrast to these floods in 2012, the entire territory of the Republic of Serbia was under the influence of drought which was characterized as extreme in most of the country. In the period from June 17th to July 16th, 2012, the average daily temperature ranged from 18 to 26°C, which is 3.5-6°C higher temperature compared to the average for that time of the year. The highest recorded temperature was in the city Loznica on August 24th, 2012 with T-max 41.0°C. Precipitation for the given period was only about 20% of the average precipitation for that period of the year

¹ US Environmental Protection Agency



(Meteorological Annual 1, 2013). Since the irrigated areas in the Republic of Serbia are among the smallest in Europe (Bogdanov, 2012), the consequences of such weather conditions were catastrophic. Direct drought consequences were visible in 2013 when the level of aflatoxin was increased in corn and livestock food (type B1(AFB1)) and cow's milk (type M1 (AFM1)) (Spirić et al., 2014). According to the unofficial data, the Government of the Republic of Serbia allocated about €150 million to redress the effects of 2012 draught, which altogether with the damage caused by the 2014 floods amounts to approximately €1.9 billion.

Aiming to support sustainable development through the provision of geospatial data and services, Republic Geodetic Authority (RGA) realized development project between 2010 and 2015 and implemented a technical infrastructure that comprises flexible, fully scalable and interoperable

components well suited for the needs of public authorities and business in Serbia.

Through the usage of a comprehensive multi-source data, and developing of capacities in the remote sensing application RGA enabled a variety of thematic maps to be produced: Generic Land Cover, Agriculture Land Cover, Natural Habitat, Landscape Fragmentation, Natural Habitat Change, Ecological Network, Natural Hazard (droughts, floods, landslides), Biophysical Parameters and other. Using of national capacities and developing of the Soil Moisture Index Map of the state on the efficient and economical way was seen as an excellent opportunity of helping the public and private sector in the field of agriculture and water management.

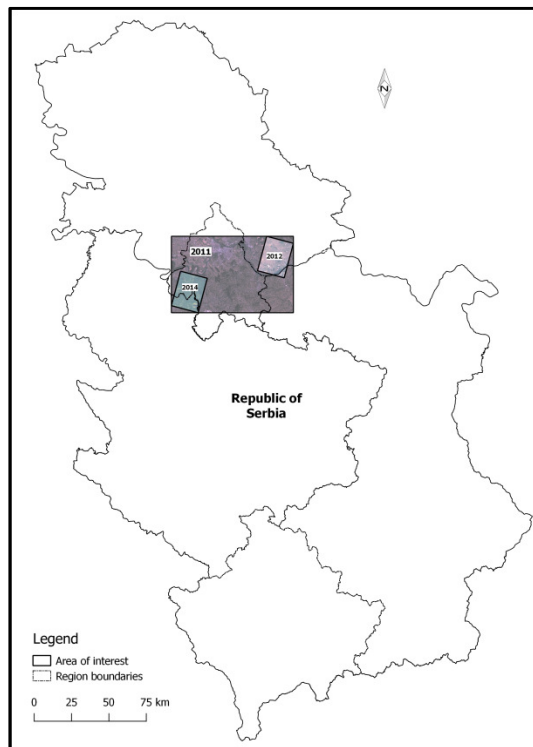


Figure 1 Area of Interest

For the area of interest two locations covering 441,87

sq km were chosen (Fig. 1). Area of interest for the drought-affected year 2012 is located in Vojvodina, covering the area north of the Danube River while the area of interest for the flood-affected year 2014 is located in the area south of the Sava River. Both areas were affected by the nature disasters in the corresponding years.



Materials and methods

Applications of the remote sensing method provide geospatial data that enables generation of adequate information related to floods and droughts when the human settlements and agricultural areas are directly affected. The method applied in this paper relies on the use of soil moisture index (SMI) which in its algorithm uses the data obtained from satellite sensors. The index is based on the actual content of water (Θ), water capacity and wilting point (Hunt et al., 2008). Multispectral satellite images from visible (red band) and infrared bands (near infrared and thermal bands) are essential for the calculation of the index. Only a few of today's satellite platforms carry sensors that can collect the data from that particular spectrum. Among these sensors, and free of charge to use, are Aster and Landsat TM, ETM+, and OLI&TIRS.

Two different satellite scenes were downloaded using USGS web application Earth Explorer. Path and row of the scenes are 186 029 from the Landsat 7 and Landsat 8 satellite. The images are dating from 30.08.2012 and 09.06.2014. Necessary bands from the scenes for the calculation are Red and Near Infrared (NIR) for the Normalized Difference Vegetation Index (NDVI) calculation and Thermal Infrared (TIR) band(s) for the Land Surface Temperature (LST) calculation. The spatial resolution of the used bands is 30 m for both scenes while the radiometric resolution is 8bit for Landsat 7 data and 16bit for Landsat 8 data and 16 days as a temporal resolution for both satellites. Map projection of the scenes is UTM Zone 34N with WGS84 datum. Selected areas of interest are cloud free. In the procedure of Landsat data preprocessing, Dark Object Subtraction (DOS1) atmospheric correction and radiometric correction were performed using QGIS SCP plugin software.

Soil Moisture Index

The algorithm that applies to the calculation of SMI function is based on the utilization of the NDVI and LST which are calculated using multispectral satellite imagery for each pixel. There are different presenting modes for SMI. Michigan Tech Research Institute (2009) presents SMI values from 0 to 1 where higher values close to 1 represent higher estimated soil moisture levels. Hunt et al. (2008) present SMI continuous data by values from -5 to 5, where $\Theta=5$ accounts for the water capacity of the field while $\Theta=-5$ is the wilting point. Further, these data can be used to create soil moisture map that can be used to define necessities for monitoring irrigation or drainage of the land. Parida et al. (2008) classify SMI values > 0.3 as no drought or favorable soil moisture conditions, whereas SMI values < 0.3 were classified into three categories of drought, namely severe, moderate, and slight drought.

In presented work, continuous SMI data ranged between 0 and 1 best describe the level of soil moisture. Therefore, MTRI (2009) method used to present mode of SMI.



Soil Moisture Index calculation

Soil moisture index is based on empirical parameterization of the relationship between land surface temperature (LST) and normalized difference vegetation index (NDVI) and calculated using following Eq. 1 (Zeng et al. 2004, Parida et al. 2008, Wang et al. 2009):

$$SMI = (LST_{max} - LST) / (LST_{max} - LST_{min}) \quad (1)$$

where LST_{max} and LST_{min} are the maximum and minimum surface temperature for a given NDVI and LST is Land Surface Temperature, the surface temperature of a pixel for a given NDVI derived using remotely sensed data.

LST_{max} and LST_{min} are calculated using following Eq. 2 and 3, respectively (Zhan et al. 2004, Parida et al. 2008):

$$LST_{max} = a_1 * NDVI + b_1 \quad (2)$$

$$LST_{min} = a_2 * NDVI + b_2 \quad (3)$$

where a_1 , a_2 , b_1 and b_2 are the empirical parameters obtained by the linear regression (a present slope and b present intercept) defining both dry and wet (warm and cold) edges of the data (Fig. 2).

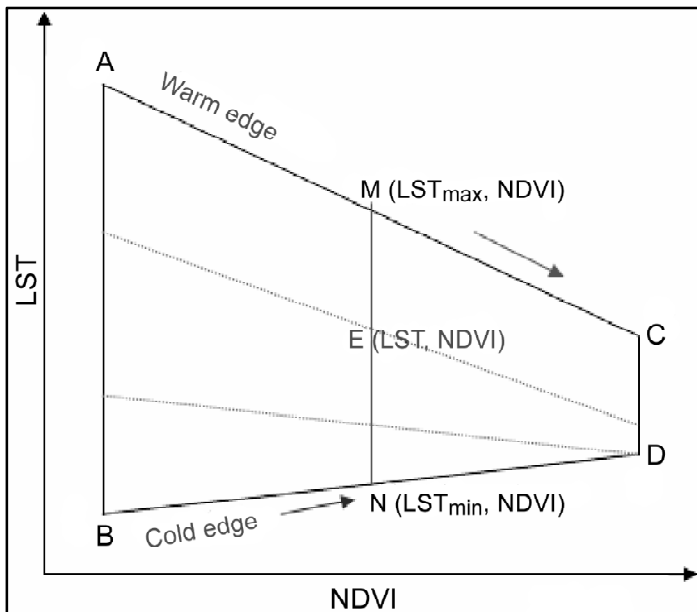


Figure 2 Definition of SMI. Scatterplot in LST-NDVI space (Parida et al. 2008)

First step in SMI calculation is the conversion of digital number (DN) to spectral radiance ($L - W/m^2/sr/\mu m$) using following Eq. 4 (Lwin 2010):

$$L = Lmin + (((Lmax - Lmin) / (QCALMAX - QCALMIN)) * (DN - QCALMIN)) \quad (4)$$



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where L_{min} and L_{max} are spectral radiance calibration constants (Table 1), $QCALMAX$ and $QCALMIN$ are the highest and lowest quantized calibration pixel values (Table 2) and DN is the Digital Number.



Table 1. Landsat spectral radiance (Lmin and Lmax) values for thermal bands

| Landsat 5 Band 6 | | Landsat 8 Band 10 and 11 | |
|------------------|------------------|--------------------------|------------------|
| Radiance minimum | Radiance maximum | Radiance minimum | Radiance maximum |
| 1.238 | 15.303 | 0.10033 | 22.00180 |

Source: NASA (2013), USGS (2015)

Table 2. Quantized calibration pixel (Qcal min and Qcal max) values

| Landsat 5 (Band 6) | | Landsat 8 (Bands 10 and 11) | |
|--------------------|------------------|-----------------------------|------------------|
| Radiance minimum | Radiance maximum | Radiance minimum | Radiance maximum |
| 1 | 255 | 1 | 65535 |

Source: NASA (2013), USGS (2015)

Two inputs must be calculated (LST and NDVI) to be able to calculate LST_{max} and LST_{min} .

LST (K) is calculated using Landsat 5 and Landsat 8 Thermal bands using Eq. 5 (Weng et al. 2004):

$$LST = T_b / [1 + (\lambda * T_b / c_2) * \ln(\epsilon)] \quad (5)$$

where: T_b (Eq. 6) is At-Satellite Brightness Temperature, λ is wavelength of emitted radiance, $c_2 = 1.4388 * 10^{-2}$ m K and it is presented with Eq. 7 and ϵ – emissivity (typically 0.95).

$$T_b = (K_2 / (\ln(K_1 * \epsilon / L + 1))) \quad (6)$$

where K_1 – sensor dependent calibration constant 1 and K_2 – sensor dependent calibration constant 2 (Table 3), ϵ – emissivity (typically 0.95) and L – spectral radiance (Lwin 2010).

$$c_2 = h * c / s \quad (7)$$

where (Weng et al. 2004) h is Planck's constant = $6.626 * 10^{-34}$ J s, c is velocity of light = $2.998 * 10^8$ m/s and s is Boltzmann constant = $1.38 * 10^{-23}$ J/K.

Table 3. Landsat 5 and 8 TIRS Thermal constants

| Landsat 5 (Band 6) | | Landsat 8 (Bands 10 / 11) | |
|--------------------|---------|---------------------------|-------------------|
| K1 | K2 | K1 | K2 |
| 607.76 | 1260.56 | 774.89 / 480.89 | 1321.08 / 1201.14 |

Source: Lwin (2010), NASA (2013), USGS (2015)

The ratio of the reflectivity differences for the NIR and the Red band to their sum (NDVI) is calculated using following Eq. 8 (Rouse et al. 1974):

$$NDVI = (NIR - Red) / (NIR + Red) \quad (8)$$

The final step in the data collecting is the determination of empirical parameters by linear regression. To do so, statistical software was developed being able to process the data for the same pixel from two raster sets, LST and NDVI, and present the distribution of the data in the scatterplot (Fig. 5). Linear regression values range from 0 at the “dry edge” (limited water availability) to 1 at the “wet edge”. Pixels close to



the dry edge are drier relative to the wet edge which are wetter (maximum evapotranspiration - unlimited water access). The scatter plot position of a pixel defines its moisture condition. The parameters are implemented in the Equations 2 and 3.

Results

NDVI (Fig. 3) and LST (Fig. 4) are calculated as necessary data to acquire SMI calculation. NDVI values are within range -1 to 1 where negative values present lack of vegetation or diseased vegetation, while positive values show healthy and dense vegetation. LST values are the surface temperature in °C.

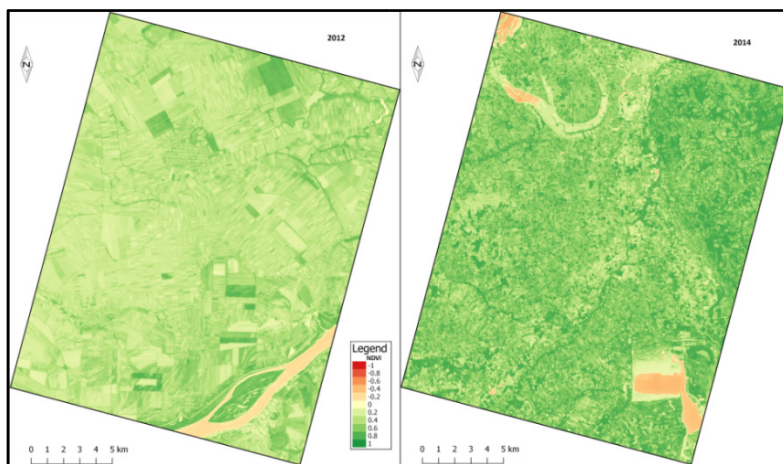


Figure 3 NDVI for areas of interest for 2012 and 2014

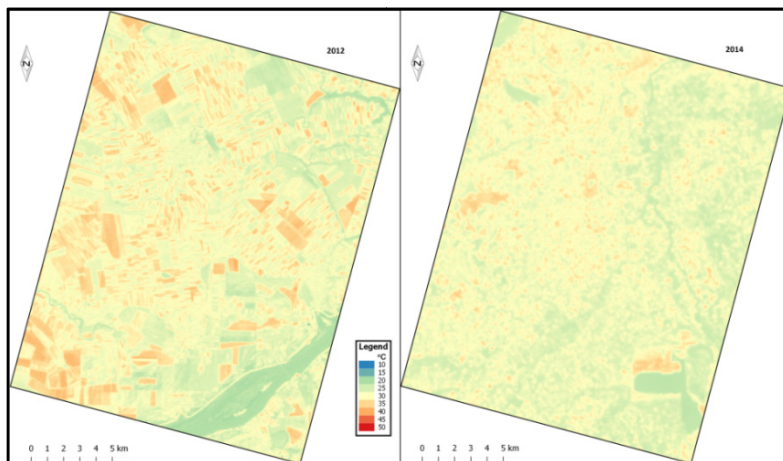


Figure 4 Land surface temperature (LST) for areas of interest

The final result from Eq. 1 is presented with the values range from 0 to 1, where values near 1 are the regions with a low amount of vegetation and surface temperature and present a higher level of soil moisture. The values near 0 are the areas with a significant amount of vegetation and surface temperature and present the low level of soil moisture (Fig. 6).



The calculation gave us following results: LST values for 2012 and 2014 are within 13.4° and 39.9°C and 23.1° to 36.7°C, respectively. The scatterplot is created only with the pixels with positive NDVI values and corresponding LST values. The LST pixels values range from 19.3° to 39.9°C for 2012 and a full range of 2014 values (Fig. 3, 4 and 5).

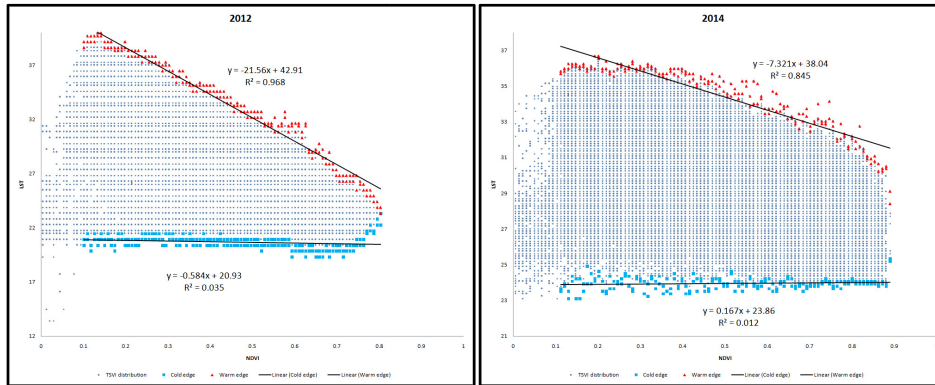


Figure 5 Scatterplots for corresponding areas of interest

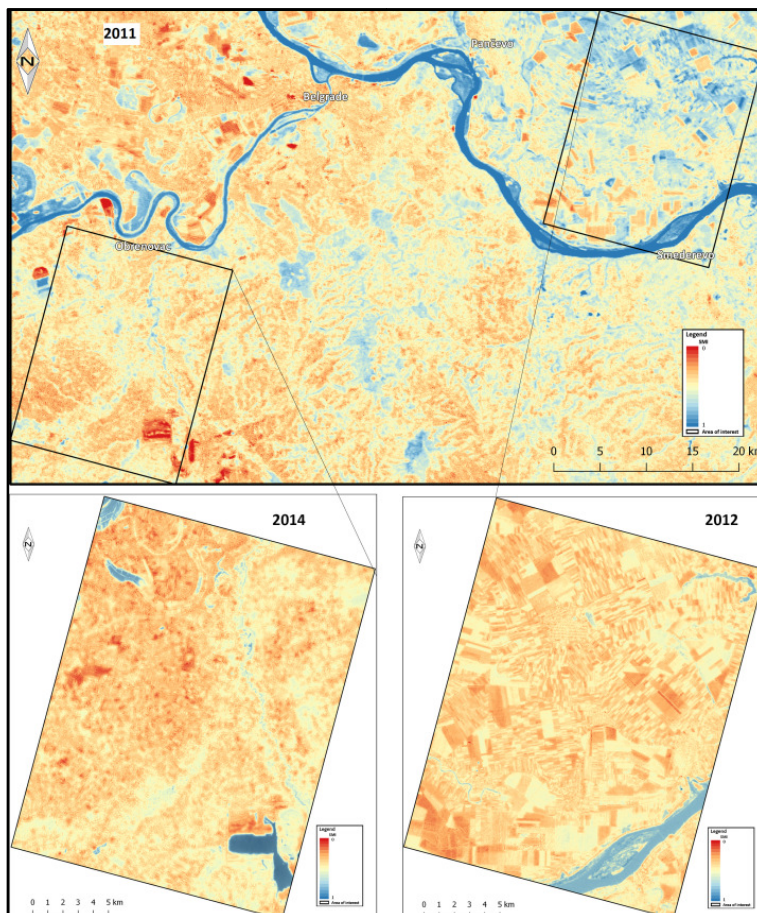


Figure 6 Soil Moisture Index maps



Fig. 6 present tree SMI maps for years 2011, 2012 and 2014. 2011 was the drought-affected year with mean summer precipitation (Climatic characteristics, 2012) and therefore is presented as a contrast to the natural disaster characterized drought-affected 2012 and flood-affected 2014. As we can see from the maps in Fig 6, 2012 has a much larger drought affected area than 2011 and huge water bodies which have occurred after the flooding in 2014. Histograms in Fig. 7 present the SMI data distribution.

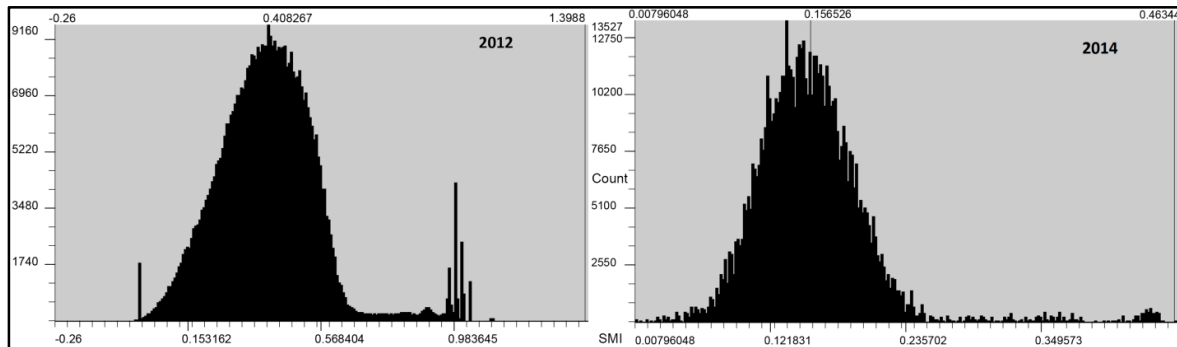


Figure 7 SMI Histograms for selected years

The most SMI values for 2012 are within 0.1 and 0.6 with mean value 0.4 and present dry state of the soil. For 2014, most of the values are within range 0.1-0.2 with a max value of 0.46 and mean value 0.16. A significant part of the 2014 area is covered by thin layer of river sediments which are dry since the flood occurrence was one month earlier than the footage was taken. As can be seen from Fig. 6 and 7, SMI can derive fast data for the affected areas. Higher values of the index present the higher water/moisture presence and lower values present dry areas.

Conclusion

Obtained results present the distribution of soil moisture. The data is in accordance with the soil condition from the corresponding periods, but more explicit confirmation of the data punctuality is necessary to verify the accuracy of the data. Field data collection would be the best option for the accuracy verification. For the flood-affected 2014, SMI has accurately depicted the surface moisture one month after the flood. As can be seen from Fig. 6 (2014), there are three major flood-affected areas compared to the 2011 map. In the south-eastern part of the map, we can see emerged lake at the site of the open pit lignite mine that did not exist in the period before the flood. In the northwest part of the map, we have the similar situation with the emerged large water bodies. The alluvial planes are presented with higher value of the index (drier areas) due to the river sediments rapid draining. The SMI values for drought-affected 2012 are also in accordance with the condition for the given period. As can be seen from the comparison to 2011 map, the entire research area has a lack of moisture in the soil. This data can be used as an excellent indicator of the soil moisture condition and can assist in



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the multi-criteria decision-making (MCDM) strategy for resolving problems with the emerged environmental stresses.

The advantages of multispectral satellite bands (visible, near and thermal infrared) in soil moisture analysis are reflected in following:

- Fine spatial resolution,
- Broad coverage,
- Satellite data free of charge,
- Low-Cost methodology,
- Good temporal resolution (USGS/NASA Landsat courtesy, 16 days),
- Ease of access,
- The possibility for the data to be improved with ground/field data.

The limitations are:

- Satellite sensors limitation (Landsat, Aster, IRMSS-2, MTI with spatial resolution up to 120m),
- Land cover dependence,
- Limited surface penetration (reflectance data),
- Cloud contamination dependence (the footage should be cloud-free),
- Verification of the results is tough without field data or complementary data (e.g., meteorological stations data).

Nowadays, when the temporal resolution of Landsat satellite images is 16 days during the year (NASA, 2013), it is possible to provide quality, accurate and up-to-date data. The data can be used for smart agricultural production planning, but also for spatial and construction planning. In the case of floods and droughts, data can be used for prevention activities related to them. The advantage of remote sensing, beside continuously derived data, is in the continuously monitoring of large areas (Shafian and Maas, 2015). SMI is potentially a very effective indicator of soil moisture with the application in irrigation scheduling and water resource monitoring.

The main agricultural problem in Serbia is the existence of a large number of small-scale farmers who are very sensitive to natural hazards. One of the priorities of the European Commission (EC) Rural Development Programmes (RDP) 2014-2020 (The Common Agricultural Policy after 2013) is promoting resource efficiency and supporting the shift towards a low-carbon and climate-resilient economy in the agriculture, food and forestry sectors. The method of this paper is consistent with the EU's Common Agriculture Policy (CAP) and helps the implementation of its integral parts: Climate-smart Agriculture (CSA), Climate-change Adaptation (CCA), Climate-change Mitigation (CCM) and Disaster Risk Reduction (DRR). Three priority action CAP areas to protect and enhance rural heritage are:

- Biodiversity and the preservation and development of 'natural' farming and forestry systems, and traditional agricultural landscapes;
- water management and use;



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- dealing with climate change (The Common Agricultural Policy after 2013).

Furthermore, this paper is in accordance with the Draft of the Country Action Programme for Serbia for the year 2017 regarding European Integration Facility through IPA II (2014-2020) which beside other, has focus on disaster risk reduction in agriculture. This work is a specific attempt to help, assist and improve the resilience of agricultural activities to climate change in Serbia. It should help in development of an early warning system and early response on national and local level; timely distribution of information which would minimize production loss; in improving prevention; and help in decision-making.

The information on natural resources and their changes are necessary for managing the policy of sustainable development. According to the UN 2030, Agenda for Sustainable Development, among 17 Sustainable Development Goals (SDGs) are: reduce poverty, zero hunger and life on land. The significance of geospatial information in the achievement of these goals is doubtless. In the future period the course of RGA capacity improvement will not be changed, and dealing with contemporary remote sensing methods will continue. Besides that, the Republic Geodetic Authority of Serbia will continue to provide up to date geospatial data and consultancy to all interested parties, both governmental and local institutions as well as regional and to cooperate with respectable organizations from all over the world.

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